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ACICULAR FERRITE AND GRANULAR BAINITE MICROSTRUCTURAL ASPECTS

MIKROSTRUKTURNÍ ASPEKTY ACIKULÁRNÍHO FERITU A GRANULÁRNÍHO BAINITU

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Abstract

Acicular ferrite (AF) is responsible for final steel properties. The same can be told about M/A (martensite/austenite) constituent being part of granular bainite (GB) microstructure in as rolled condition. Both mentioned austenite transformation products are formed by displacive mechanism being connected with higher dislocation density. In paper, attention has been devoted to AF, its microstructural parameters, substructure, fractography characteristics and hydrogen response. Further, acicular ferrite properties have been compared with similar ones detected in M/A constituent.

Abstrakt

Acikulární ferit (AF) je zodpovědný za finální vlastnosti oceli. Totéž lze říct o M/A (martensit/austenit) složce, která je součástí mikrostruktury granulárního bainitu (GB) ve stavu po doválcování. Oba zmíněné produkty transformace austenitu vznikají displacivním mechanismem a jsou spojeny se zvýšenou hustotou dislokací. V práci je zaměřena pozornost na AF, jeho mikrostruktuní parametry, substrukturu, fraktografické charakteristiky a vodíkovou odezvu. Následně jsou vlastnosti acikulárního feritu srovnávány s obdobnými vlastnostmi detekovanými v M/A složce.

Key words: acicular ferite, granular bainit, M/A constituent, substructure

1. Introduction

Acicular ferrite (AF) and M/A (martensite/autenite) constituent are originated by displacive mechanism. The AF is formed at the similar temperature as upper bainite, practically while the AF plates (laths) are nucleated at nucleable particles, intragranularly. After faster cooling process up to 30 °C in second, AF microstructure is realized at temperature of 500 °C, approximately. Woven, chaotic microstructure is typical for AF being responsible for generally favourable toughness. Comparable strength properties with detected ones in upper bainite are ascribed to displacive mechanism of AF formation [1].

The granular bainite (GB) is formed in temperature interval slightly higher than that of the upper bainite [2]. At faster cooling rates a steep carbon concentration gradient is developed in the austenite, which is highly supersaturated with carbon [2]. Consequently, cementite precipitation occurs at ferrite-austenite interface during the transformation process. This corresponds to the well known feature of the upper bainite. On the contrary to these conditions, at ferrite-austenite interface the carbon concentration is lower, when relatively low carbon rates are used. During the continuous cooling of steel the M/A constituent is formed in GB being responsible for degradation of toughness under the tensile stress [3]. The aim of this work is a microstructures comparison of above mentioned displacive mechanism products being responsible for final steel properties.

2. Experimental procedure

Chemical compositions of two analysed steel types in Tab. 1 are presented. Material with acicular ferrite represents continuous cast slab after intensive cooling with water showers (to 800 °C) and compressed air further about 350 °C having 125 (thickness) x 800 (width) mm in dimensions. The second studied material corresponds to flange of the U-profile of 100 x 50 mm in dimensions. Flange thickness equals 12 mm unlike the web being of 18 mm. These thickness disproportions have led to different cooling conditions from the final rolling temperature (1050 °C) and consequently to different M/A constituent volume fraction.

Table 1 Chemical compositions of used material (wt. %). AF represents matrix with AF and pearlite, M/A represents GB matrix with M/A constituent

Material	C	Mn	Si	S	P	Mo	Nb	Alc	Alk
AF	0.19	1.34	0.19	0.008	0.014	-	-	0.032	0.025
M/A	0.08	1.75	0.40	0.003	0.020	0.25	0.05	0.028	0.022

In addition to the conventional light microscopy in case of both materials, for the reliable detection of the M/A constituent in granular bainite a special etching technique was used. The special etching agent is based on the 4% C_2H_3OH picric acid solution and 1 % water solution of $Na_2S_2O_4.2H_2O$. The volume fraction, distribution and size of the M/A constituent were determined. Further, for both studied materials using transmission electron microscopy (TEM) of thin foils (JEM-200CX) in bright and dark field dislocation density was determined both in M/A constituents and in acicular ferrite plates. Simultaneously, the microfractography analyses of fracture surfaces of Charpy V notch impact specimens was performed. In case of granular bainite microstructure the carbon concentration was measured in the M/A constituent areas using micro-analyser (Philips SEM equipment with WDA). Granular bainite (GB) is originated at slightly higher temperature than corresponds to upper bainite formation.

Fig. 1 Micrograph of slab showing general view of acicular ferrite plates (nital – x100)

Fig. 2 Micrograph of slab – acicular ferrite with pearlite filling - in detail (nital – x2800)

3. Results and discussion

Micrograph image of slab is presented in Fig. 1. Figure 2 shows its detail. In average about 67 % of AF was detected in microstructure, situated intragranularly solely. The AF plates (laths) are nucleated on specific non-metallic particles [4-6]. Of course, austenitic grains were also decorated with discontinuous allotriomorphic ferrite, being both active and inactive and inside the austenitic grains few idiomorphic ferrite were detected, too. Pearlite filling is part of microstructure. Primary austenite grain size corresponds to 280μm in average.

After etching in nital, flange and web microstructure show none differences, practically with exception of coarser microstructure in case of web as it follows from Fig. 3 and Fig. 4. However after etching in special etching agent mentioned above important changes can be observed. The white areas correspond to M/A constituent being situated about primary austenite grain boundaries and regarding web in interior of those grains, too. In case of web M/A volume fraction amounted to 29 %, in case of flange it was to 7 % only, how can be seen in Figs. 5 and 6. Generally, slower cooling process is connected with higher volume fraction of M/A constituent and higher thickness of web how was elucidated former [7]. The maximum M/A constituent particle size of web attains 6μm on the contrary to flange, where the size is only 1-2μm and the particles are more uniform. The block-form of M/A constituent was found in majority cases and its rod-form was observed rarely.

Fig. 3 Micrograph of web (nital – x500)

Fig. 4 Micrograph of flange (nital – x500)

Fig. 5 M/A constituent in web

Fig. 6 M/A constituent in flange

(special etchant – x500)

Figures 7 and 8 demonstrate AF micrographs (TEM). The AF forms prolonged plates (laths) with uneven grains (high angle boundaries). Those plates are divided by dislocation walls into sub-grains showing the average dislocation density of $1.1.10^{14}$ m^{-2}. The higher AF dislocation density is supposed to contribute to general favourable hydrogen induced cracking resistance how was already presented recently [8, 9].

Substructure of M/A constituent represent Fig. 9 and Fig. 10. As it is seen in those figures the internal twinning in martensite plates was found. This one is characteristic for the high carbon martensite. The carbon concentration measured in areas of the M/A constituent (WDA) is 0.60% approximately. Dislocation density of the M/A constituent corresponds to 5.10^{14} m^{-2}.

The AF plates (laths) form woven, chaotic structure resulting in favourable toughness [9-11]. Typical acicular ferrite fracture surfaces Fig. 11 and Fig. 12 demonstrate. Fracture surface shows even dimple features with 2.4μm average dimple diameter. In case of GB results of the microfractography analysis corresponds to the determined different values of the impact toughness of specimens taken from the web and flange. The fracture surfaces have a cleavage feature and the intergranular fractures are not observed. The average dimension of fracture facets corresponds to 20μm in the case of web as can be seen in Fig. 13. On the contrary the average dimension of flange cleavage facets is 7μm (Fig. 14) with higher occurrence of ductile ridges. In Figs. 11-14 fracture surfaces of Charpy tests at 0 °C (KCV_0 – impact test) are presented.

Figs. 7 and 8 Micrographs of acicular ferrite substructure (TEM – x20 000 and x10 000)

Fig. 9 Substructure of martensite in the M/A constituent - bright field image (112)α′

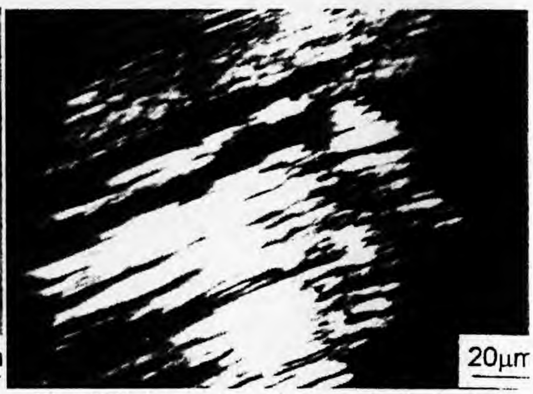

Fig. 10 Substructure of martensite in the M/A constituent - dark field image (112)α′

4. Conclusion

The work acicular ferrite and M/A constituent being granular bainite product are compared. The both microstructures phases are formed by displacive mechanism. Acicular ferrite demonstrates a high dislocation density ($1.1.10^{14}$ m^{-2} in average). It can be held for further hydrogen traps in case of hydrogen resistance evaluation. Further, results show 7.5 times higher carbon content in M/A constituent being evidence of high carbon martensite. It was confirmed through substructure of M/A constituent plate. Dislocation density of the M/A constituent corresponds to $5.10^{14}.m^{-2}$.

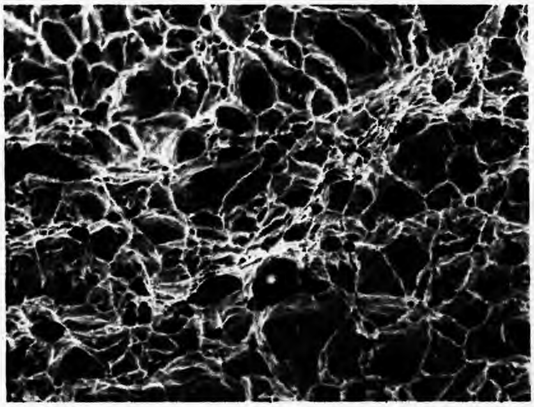

Fig. 11 Fracture surface of AF (KCV_0 – x700)

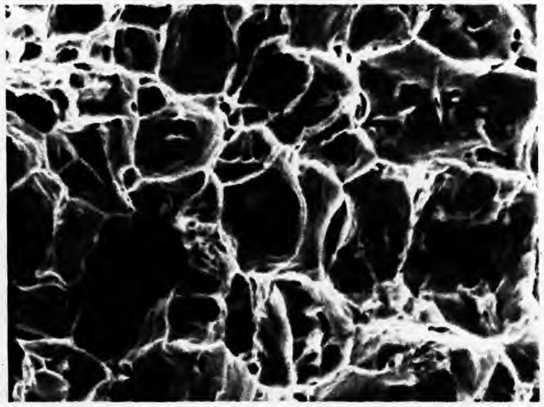

Fig. 12 Fig. 11 in detail (x1500)

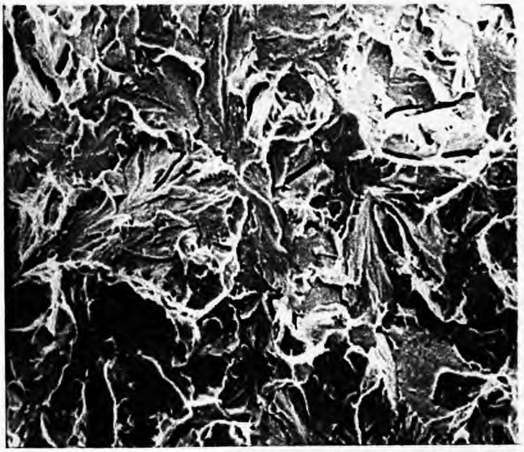

Fig.13 Fracture surface of web (KCV_0 – x500)

Fig. 14 Fracture surface of flange (KCV_0 – x500)

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